

**Research Synopsis**  
**Pinaki Sengupta, April 2007**

My research interests lie primarily in exploring the physics of strongly interacting quantum many body systems in reduced dimensionality. Some representative examples of problems I have worked on include the study of quantum phase transitions in interacting electrons on a lattice, Heisenberg spin systems with spin-lattice interactions, and bosonic systems with or without an external trap. Currently, I am actively pursuing the following projects.

*Supersolid phase in lattice systems:* The supersolid is a novel phase of matter that has simultaneously solid and superfluid character. The indications of such a state in recent experiments on solid  $^4\text{He}$ <sup>1</sup> has led to a resurgence of interest in the search for supersolid phase in bosonic systems. Previously, we had identified the conditions under which such a phase can be realized in the ground state of interacting bosons with extended range interactions. Recently, we have extended the search for this novel phase of matter to spin systems. We have demonstrated that a thermodynamically stable supersolid phase can be obtained in a model of interacting  $S=1$  dimers on a plane with an externally applied magnetic field. The most interesting aspect of the study is that the model is experimentally realizable in transitional metal compounds. I plan to continue to study in greater detail the mechanisms leading to the formation of the super-solid phase and determine the optimal conditions under which it can be observed experimentally in quantum magnets. In addition, I want to investigate the possibility of supersolid phase in bosons with long-range dipolar interaction, and formulate the experimentally observable signatures of such a phase in these experiments.

*Spin systems:* I collaborate closely with the experimentalists at the National High Magnetic Field Laboratory (NHMFL) at LANL to study interacting spin systems in various lattice geometries. Recent experiments at the magnet lab has revealed several fascinating new results. The first experimental observation of dimensional reduction due to geometric frustration in  $\text{BaCuSi}_2\text{O}_6$  is one example. The BEC of Ni spins in  $\text{NiCl}_2\cdot 4\text{SC}(\text{NH}_2)_2$  is another. I plan to develop a theoretical framework that will explain the novel experimental results in these materials as well as suggest new experiments. Some of the specific projects I am involved in are as follows:

(a) *Magnetostriction in DTN:* The compound DTN shows unique magnetostriction in an external magnetic field that can be measured accurately. We demonstrated that this can be used to estimate the magnetic energy along the corresponding axis. To the best of our knowledge, this is the first proposed method of directly measuring the magnetic energy in a compound.

(b) *ESR in DTN:* ESR measurements at different temperatures and magnetic fields yield a wealth of information about the ground state as well as excited states of any compound. We are using theoretical modelling and numerical diagonalization to analyze the ESR data in DTN to elucidate the nature of excitation spectra.

(c) *Specific heat of quasi-2D compounds:* Layered compounds like copper pyrazine perchlorate exhibit unique signatures in specific heat measurements at high magnetic fields. The application of an external field changes the symmetry of the Cu spins from  $\text{SU}(2)$  to XY. This, in addition to the effects of inter-layer couplings that also depend on the applied field, lead to these novel features. We are using large scale QMC simulations to explain the mechanisms behind these phenomena.

(d) *The orthogonal dimer Heisenberg compound  $\text{SrCu}_2(\text{BO}_3)_2$ :* The highly frustrated Shastry-Sutherland compound exhibits several magnetization plateaus with varying applied field. This has been the focus of intense theoretical and experimental studies over the past few years. We are using the Chern-Simons theory with local density fluctuations to study the properties of this material at high magnetic fields and identify the spin density profiles at the magnetization plateaus. Our results show excellent agreement with the experiments currently being conducted at the Magnet lab.

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<sup>1</sup>E. Kim, and M. H. W. Chan, Nature **427**, 225 (2004), Science **305**, 1941 (2004)